Well Injection Depth Extraction (WIDE) for Subsurface Mixed Waste Flushing

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Introduction

Contamination in low permeability, high clay fraction soil poses a significant technical challenge to *in situ* remediation efforts. Traditional technologies such as pump-and-treat groundwater remediation and vapor extraction using well fields have been rather ineffective when applied to sites with low permeability soils. The extraction of the contaminant from the soil and movement of the flushing solution are restricted due to the pore size, soil fabric arrangement, and adsorption characteristics of the fine-grain soils.

An innovative subsurface remediation technology termed Well Injection Depth Extraction (WIDE) has been developed and demonstrated by North Carolina State University (NCSU). The WIDE system is a hybrid subsurface flushing/vapor extraction system that uses Prefabricated Vertical Wells (PVWs) for the *in situ* remediation of contaminated groundwater and fine-grained soils with hydraulic conductivities ranging from 10^{-3} to 10^{-8} cm/s. The WIDE system is suitable for removal of soluble contaminants in groundwater, dense non-aqueous phase liquids (DNAPLs), and light non-aqueous phase liquids (LNAPLs).

Problem

The US Department of Energy's Ashtabula Environmental Management Project (AEMP) is located in Ashtabula, OH, on property owned by RMI Environmental Services (RMIES). The site's groundwater and soils are contaminated with Trichloroethylene (TCE), Uranium (U), and Technetium-99 (^{99}Tc) which resulted from long-term uranium manufacturing operations for use within the DOE's weapons complex.

The subsurface remediation at the site is technically challenging due to the glacial till soil exhibiting *in situ* hydraulic conductivity of approximately 10^{-6} cm/s, with a clay fraction of 60% as well as the mixed nature of the waste. The TCE and U concentrations in the groundwater ranged approximately 440,000 ppb TCE and 13,000 ppb U. Until recently the only corrective action proposed to address the site's soil and groundwater condition has been the use of traditional pump-and-treat systems with remediation time frames in excess of 40 years.

Solution

The WIDE system has been demonstrated at DOE's Ashtabula Environmental Management Project (AEMP) beginning January 1997 through December 1999. A multi-phased project structure was used for progressing the WIDE technology into a deployment stage to assist RMIES with the groundwater and soil cleanup effort. The first phase consisted of a field investigation, predictive modeling, data review, and limited laboratory sample characterization. This work was followed by field construction and operation of a pilot-scale test pad. Phase II, discussed in detail in this reprot, was the full demonstration of the WIDE technology at the RMIES facility.

The goals of the demonstration project were to:

- design, construct, and operate a full-scale WIDE system in a low permeability, high clay-fraction, glacial till soil.
- evaluate the capabilities of WIDE to remediate soil and groundwater having hazardous and radioactive contamination from TCE, U, and ^{99}Tc.
- investigate contaminant reduction levels and limits for end-point remediation capability using the WIDE system.

The field-scale demonstration of the WIDE system measured one-tenth acre, 70 ft. x 70 ft., and included a grid of over 480 PVWs installed to a depth of 15 ft. A photograph of the demonstration system at DOE's AEMP is presented below in Figure 1.

The major elements of the WIDE technology include:

- Prefabricated Vertical Wells (PVWs)
- Groundwater and soil vapor vacuum extraction system
- Liquid injection system
- Above-ground treatment system

Figure 1. WIDE Demonstration System

Prefabricated Vertical Wells (PVWs)

Prefabricated Vertical Wells (PVWs) were developed on the existing platform of prefabricated vertical drains, or known more commonly as wick or strip drains. Prefabricated vertical drains are an existing geotechnical engineering technique that has been routinely used since the mid-50's for soil (silt and clay) improvement and de-watering of mine tailings.

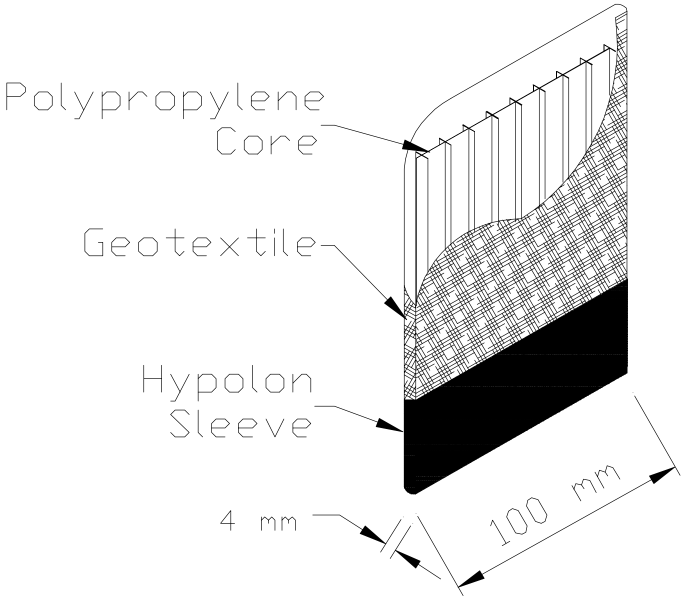

Figure 2 - Cross section of a PVW.

The PVW is manufactured as a composite system of an inner core, an outer permeable filter jacket, and at specified positions, an impermeable barrier sleeve. This geosynthetic composite is illustrated in Figure 2.

The PVW typically measures 100 mm wide by 4 mm thick. The core is constructed of extruded polypropylene and the filter jacket is typically a durable, non-woven polypropylene geotextile. The impermeable sleeving is a reinforced high-density polyethylene, a unique characteristic of the PVW. This design feature enables selective depth specific extraction and injection capability.

The WIDE system incorporates the PVWs as the mechanism for pressurized injection of a flushing solution into the *in situ* soil concurrent with vacuum extraction for removal of the contaminated solution. The PVWs shorten the groundwater drainage path, promoting subsurface liquid movement and thus expediting the soil flushing process (illustrated in Figure 3).

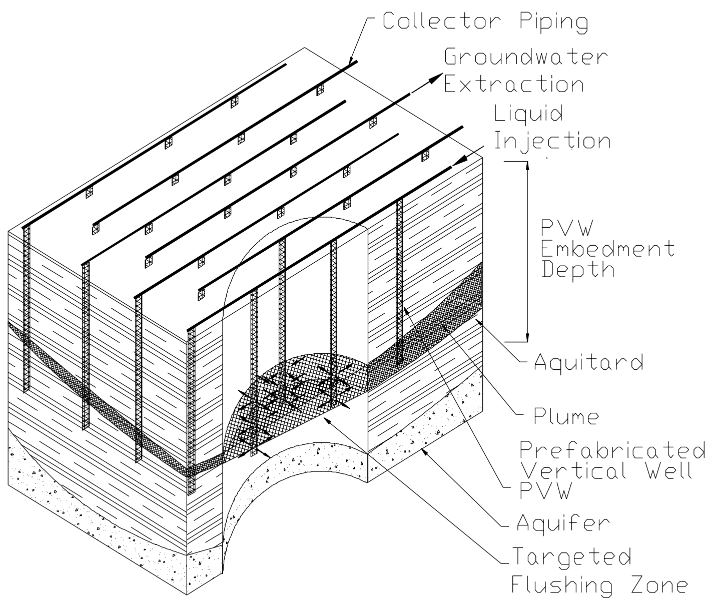

Figure 3 - WIDE soil flushing system.

Balancing injection and extraction groundwater volume diminishes the potential for inducing a volumetric change in the soil, thereby reducing the hydraulic conductivity and increasing the flushing time. The PVWs are installed using a device patented by the Nilex Corporation, Denver Colorado. The Nilex process uses a hollow steel mandrel which typically measures approximately 120 mm in width by 30 mm in depth with lengths exceeding 30 m. The PVWs are positioned within the hollow core of the mandrel. Then, the steel mandrel is pushed into site soil under hydraulic or vibratory forces at rates of 3 m/s in firm clay. A typical 7 meter (20 ft) deep PVW installation requires approximately 4 seconds.

Field construction typically entails a triangular grid of PVWs in offset rows of injection/extraction lines at relatively close spacings (< 1 meter). The interval spacing and offset between the injection/extraction dedicated PVWs are based on engineering design and modeling. The PVWs are connected to a surface network of piping that is used for distributing the air vacuum, receiving the extracted groundwater, and introducing the injection liquids.

The WIDE system may function under the following operational approaches:

<u>Concurrent PVW injection/extraction</u>. This mode is for an aggressive soil flushing scheme. Injection of liquids to the subsurface through the PVWs develops a cone of mounding in the aquifer, promoting advective groundwater movement, essentially pushing the contaminated groundwater to the extraction PVWs.

<u>Injection Only:</u> Here the PVWs are used to saturate the subsurface promoting contaminant solubilization.

<u>Extraction Only:</u> All of the PVWs operate under air vacuum specifically for aquifer depletion to promote soil vapor extraction. This technique has proven to be effective for removing volatile contaminants.

Results

The WIDE system successfully extracted TCE, U, and ^{99}Tc from the subsurface, thereby reducing the concentration of these contaminants in the groundwater. Under extraction only operation, TCE removal was enhanced by volitilizing TCE from soil surface. The system was able to exchange pore volumes of groundwater through the sites low permeability soils. Injection of liquids through PVWs with concurrent extraction was found to increase groundwater extraction flowrates and enhance the removal of dissolved contaminants

Observations of system performance from the Extraction Only operation indicated the following:

- The groundwater extraction flowrate ranged from 25 gal/hr to 150 gal/hr. Typically, the flowrate decreased over a six hour operation period.
- The air flow rate increased from an initial rate of 120 cfm to 350 cfm over the 6 hr operation period as the groundwater flowrate decreased.
- The local groundwater elevations lowered during the 6 hr operation period with subsequent recovery occurring over the18 hr off-cycle.
- At an average flowrate of 125 gal/hr, the WIDE system was able to exchange one pore volume of groundwater in 258 hours of non-continuous operation (43 days at 6 hours per day).

Under the extraction only mode, TCE removal occurred first in the soluble phase with the extracted groundwater, then as the groundwater elevation was lowered, TCE was volatilized from the soil surface and removed in the vapor phase. TCE recovery from Quadrant 4 consistently produced removal rates of approximately 7 grams/hr of TCE (gas and liquid phase). Figure 4 presents cumulative TCE removal, (mass basis), versus cumulative run time.

Remediation of the uranium constituent occurred as a result of groundwater extraction. Uranium recovery increased with increasing groundwater extraction rates. Uranium removal rates as high as 0.6 g/hr where observed.

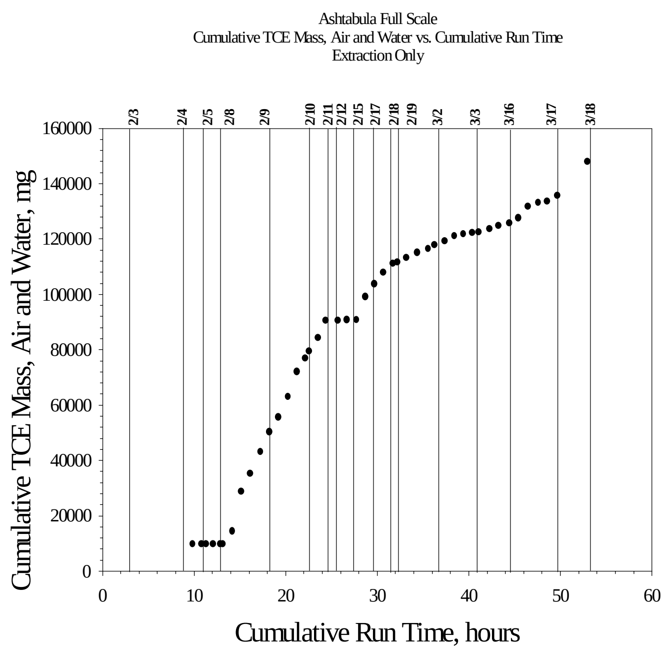

Figure 4: Quadrant IV, TCE Mass Removed vs. Cum. Run Time

Groundwater Monitoring Well Results

The TCE and U groundwater concentrations were monitored in each quadrant and at the upgradient / downgradient locations to pace the response of the WIDE system operation. Graphs of grab sample contaminant concentrations from select groundwater monitoring wells were obtained. Data for Quadrant III are presented versus the WIDE system operating time in Figure #5a and 5b.

The #503 groundwater monitoring well concentration prior to operation of the WIDE system is 433,000 ppb (µg/L). After 31 hours of actual WIDE operation during a 261 hour monitoring period, the groundwater contaminant level reduced to 150,000 ppb, a reduction of 65%. Similarly for the Uranium contaminant, Figure 6B, the initial concentration reduces from 18000 ppb to 7000 ppb, a 61% reduction during the same 31 hour operating time.

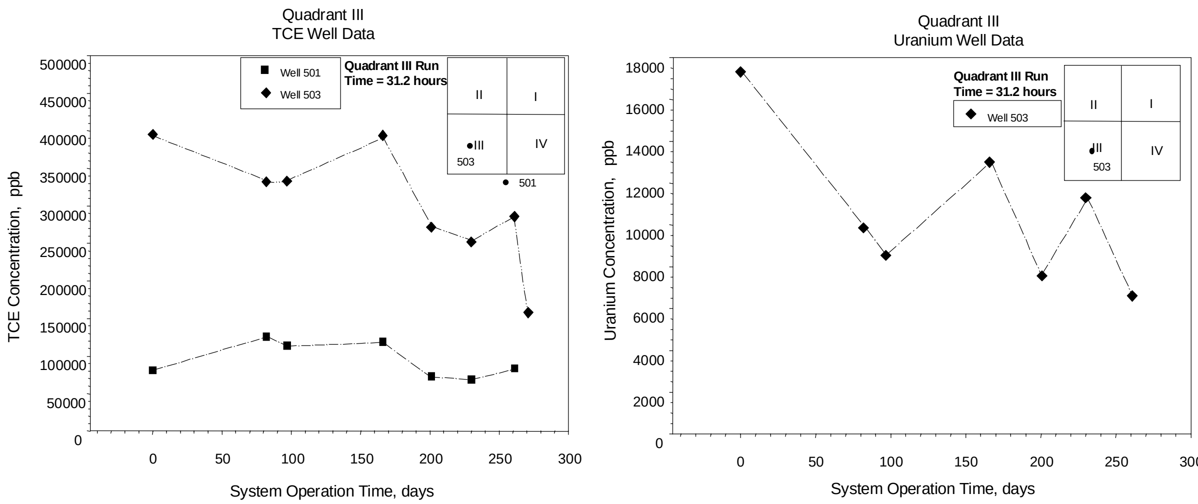

Figure 5 - Quadrant III
A)TCE Well Data, B) Uranium Well Data

In Table 1., the groundwater monitoring well results are presented for the first six month operating period. Quadrants I thru III recorded reductions in the TCE groundwater concentrations ranging from 65% to 80% with contaminant concentration levels as high as 420,000 ppb for operating times between 31 to 54 hours. In Quadrant IV, a 57% reduction in TCE was achieved at a concentration level of 2,800 ppb in 380 hours of operation.

Table 1. Groundwater Well Performance

Groundwater Monitoring Well #	Quadrant #	Vacuum System Operating Time (hours)	TCE Contaminant Reduction Range - Groundwater	TCE Percent Reduction
506	I	54	Hi 105,000 ppb Low 20,000 ppb	80%
507	II	89	Hi 140,000 ppb Low 35,000 ppb	75%
503	III	31	Hi 420,000 ppb Low 175,000 ppb	65%
502	IV	380	Hi 2,800 ppb Low 1,200 ppb	57%

Application

The WIDE technology is applicable for the *in situ* remediation of contaminated fine-grain fraction soils (clay/silts) with hydraulic conductivities ranging from 10^{-3} to 10^{-8} cm/s. Demonstration of the WIDE system showed that this innovative system removed subsurface TCE, U, and ^{99}Tc contamination by extracting groundwater and soil vapor from the low permeability, high clay, soils. The WIDE system also proved capable of injecting liquids into the subsurface to enhance the soil flushing process.

The WIDE technology has demonstrated the benefit of effectively reducing source point plume concentration and offering the capability of contaminant source containment and control based on its capability of achieving large contaminant concentration reductions within relatively short operational times. Its soil flushing capabilities are suitable for removal of dissolved-phase contaminants, dense non-aqueous phase liquids (DNAPLs) and light non-aqueous phase liquids (LNAPLs).

Future Activities

The WIDE system is progressing to deployment at the DOE AEMP during FY00. The project is moving to full commercialization by the Nilex Corporation - Denver, CO; manufacturer and installer of the PVWs.

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